Testing the retrieval of atmospheric change from spectral radiance change

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Outline of this presentation

- Describe the method of simulating the atmospheric retrieval process.

- Summary of necessary conditions to retrieve atmospheric property changes by a linear regression.

- Test the retrieval of atmospheric properties from the spectral difference of 2 years of control run.

- Result of extracting temperature and humidity profile changes from a spatially and temporally averaged spectral change is encouraging but more work needs to be done especially for extracting cloud property changes.

Our approach

- Focusing near term changes instead of changes occur by doubling the carbon dioxide concentration

- Use observed cloud properties.

- Averaging instantaneous nadir view radiances instead of taking monthly mean atmospheres and cloud fields.

Spectral radiance computations

- MODIS derived cloud properties
- Temperature and humidity profiles are from GEOS-4 (reanalysis)
- Control (unperturbed) run is from 2003 through 2006
- Nadir view only
- Spectral radiance change is computed by perturbing 2003 and 2004 atmospheres
- TOA spectral radiances are computed with a 20 km spatial resolution for every CERES nadir view footprints.

TOA flux variability from CERES
## (monthly deseasonalized anomalies)
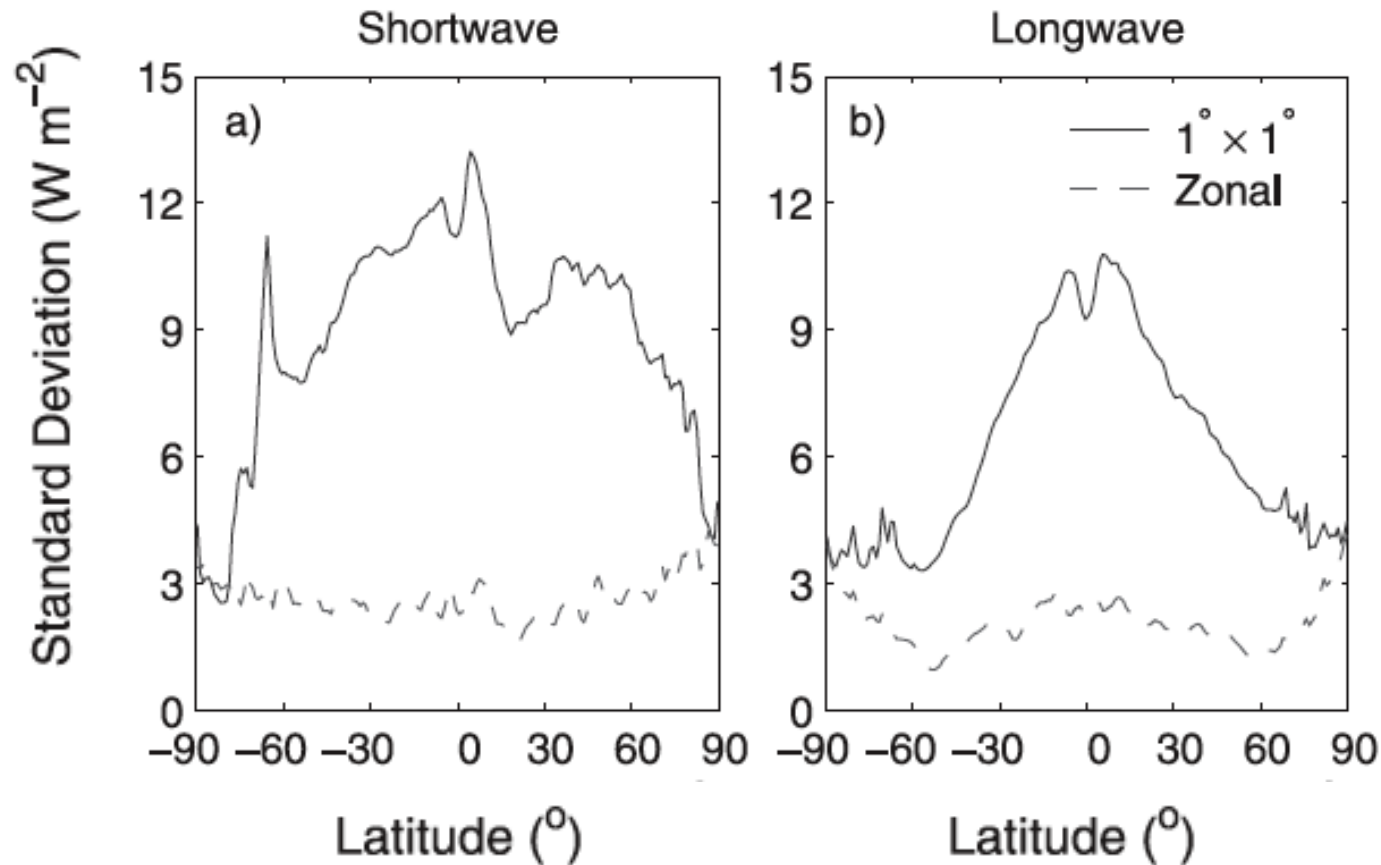
Global 0.5 Wm^{-2} (SW) and 0.4 Wm^{-2} (LW)   Kato *J Climate* 2009

Atmospheric property perturbations to compute TOA spectral change

1. Skin & near surface air temperature **plus 0.20K**
2. Stratospheric Temperature 200-10mb **minus 0.2K**
3. Troposphere Temperature Sfc-200 **plus 0.2K**
4. Low Cloud Area **minus 2.5%**
5. Mid Cloud Area **minus 2.5%**
6. High Cloud Area **minus 2.5%**
7. Low Cloud Height **minus 250 meters**
8. Mid Cloud Height **minus 250 meters**
9. Hi Cloud Height **minus 200 meters**
10. Thin Ice Cloud optical depth **times 1.30** *for optical depth < 1.0*
11. Water cloud optical depth **times 1.10**
12. Ice Cloud particle size D_e **plus 1μ**
13. Water cloud particle size R_e **plus 1μ**
14. 200-500hpa water vapor **times 1.025**
15. Sfc-500hpa water vapor **times 1.025**

Temperature

Cloud properties

Water vapor
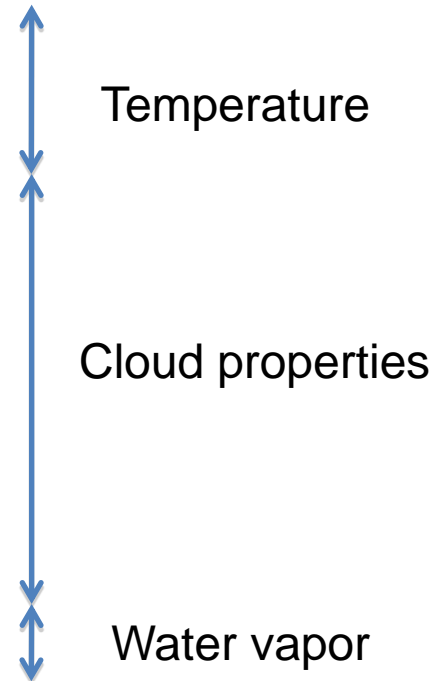
- **Many more spectral shapes will be necessary to cover the observed spectral radiance change.**

- **A higher vertical resolution to the perturbations of clouds, temperature and humidity profiles helps. The current resolution is due to computational convenience.**

Atmospheric temperature and water vapor change

	NCAR model[1] CAM3.0 (SRESA1B)	Our perturbation	Std. Dev. of 10 deg. Zonal monthly mean diff.[2]
Skin and Surface air temperature	+0.27 K	+0.2K	1.19K
Upper Tropospheric Relative humidity (200-500mb) (relative change)	+3.16%	+2.5%	2.27%
Upper troposphere and Stratospheric Temperature 200-10mb	+0.15K[3]	-0.2K	1.34K
Tropospheric Temperature below 200mb	+0.31K	-0.2K	0.45K
PW below 500mb (relative change)	+1.63%	+2.5%	4.87%

[1]Difference between 1st and 2nd decades
[2]Computed from 2003 and 2004
[3] Mass weighted mean change

Cloud change

	NCAR model[1] CAM3.0 (SRESA1B)	Our perturbation	Std. Dev. of 10 deg. Zonal monthly mean diff.
Global annual mean cloud fraction	0.00045		
Low cloud fraction(0-3.5km)		0.025	0.021
Mid cloud fraction(3.5-6.5km)		0.025	0.010
High cloud fraction(6.5-20km)		0.025	0.018
maximum monthly (among 12 months) cloud fraction change			
total (low+mid+high) global	0.0063		
total (low+mid+high) regional			
Antarctic	0.0115		
SH midlatitude	0.0050		
tropics	0.0054		
NH midlatitude	0.0095		
Arctic	0.0195		

Cloud property perturbations

	Our perturbation	Std. Dev. of 10 deg. Zonal monthly mean diff.
Low level cloud height	0.25 km	0.39 km
Mid level cloud height	0.25 km	0.15 km
High level cloud height	0.2 km	0.21 km
Ice De	1.0 μm	4.47 μm
Water Re	1.0 μm	1.54 μm
Ice cloud optical depth	30%	32%
Water cloud optical depth	30%	0.9%

Difference between Combined run and
sum of individual runs (non-linearity term, Huang et al. 2010)

Global

Zonal (12 month ave.)
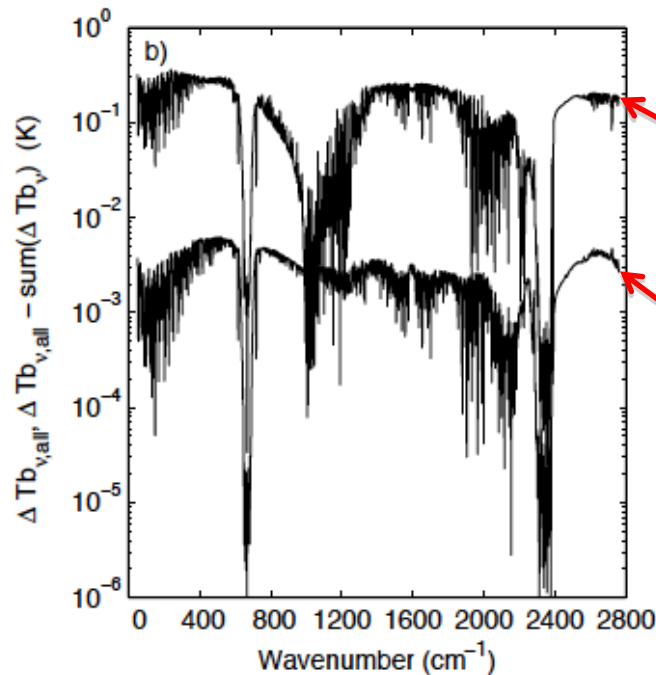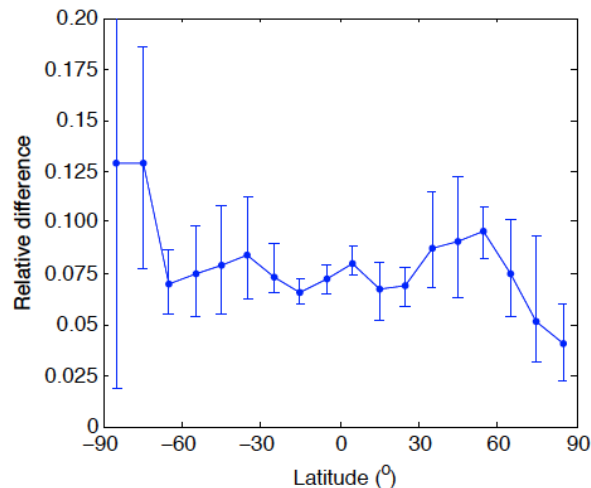
Temperature, humidity, and clouds
are perturbed together
(combined run)

Combined run
– sum of individual runs

RMS difference of the sum of spectral difference from
all individual perturbations and the spectral difference perturbed all at once
computed with10 degree zonal means is **7%**
The maximum and minimum differences is **24%** and **2%**, respectively

Linearity of TOA spectral change to atmospheric perturbations
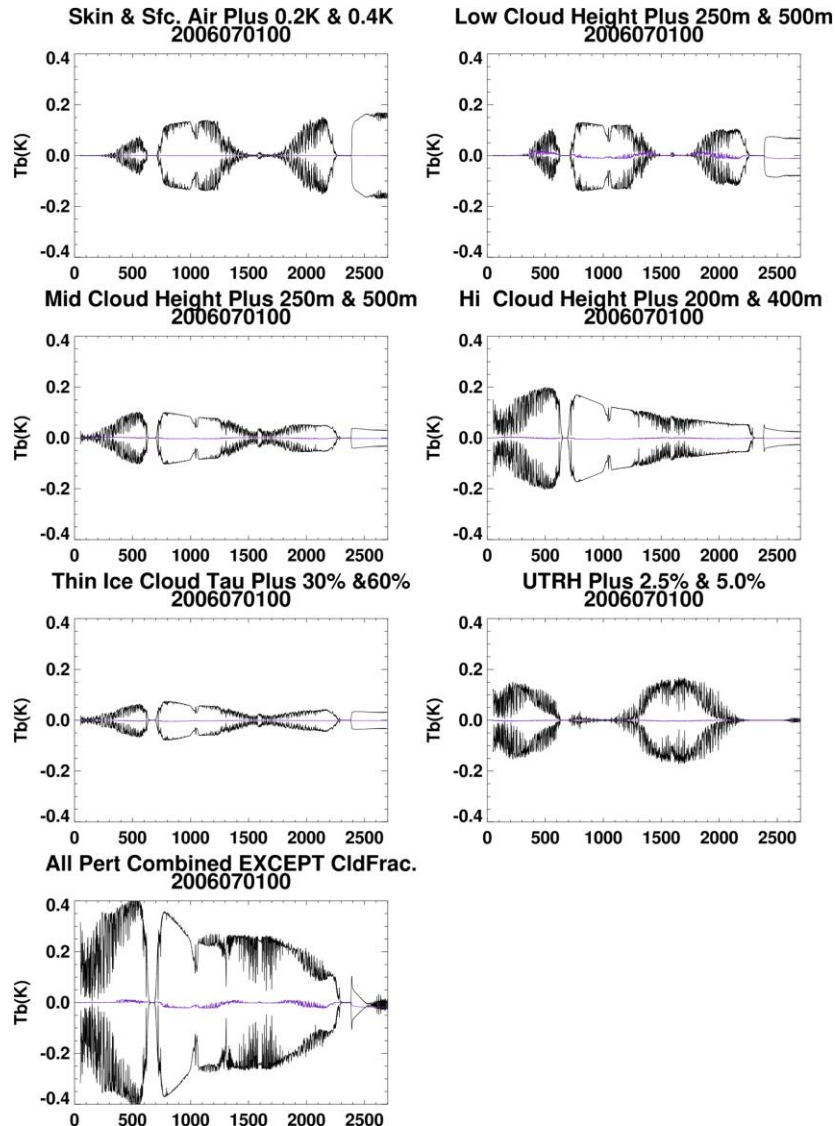
Upper line: 2Δ-Δ
Lower line: control –Δ

Blue line: (2Δ-Δ) – (Δ - control)

Linear regression results
## (linear regression is applied to the spectral radiance change computed by perturbing all at once)

	Truth	w/o non-linear term	With non-linear term
Skin & Sfc. air temp plus 0.20 K	1.0	0.9276	1.0
Low cloud height plus 250 m	1.0	1.0596	1.0
Mid cloud height plus 250 m	1.0	0.8695	1.0
High cloud height plus 200 m	1.0	1.0078	1.0
Ice cloud tau plus 30%	1.0	0.9169	1.0
UTRH plus 2.5%	1.0	0.9973	1.0
Low Cloud Fraction minus 2.5%	1.0	1.2533	1.0
Mid Cloud Fraction minus 2.5%	1.0	0.9808	1.0
High Cloud Fraction minus 2.5%	1.0	1.0226	1.0

Spectral shape is sufficiently unique to perform a linear regression

$$\overline{I(x)} \neq I(\bar{x}) \quad \text{and} \quad \overline{\frac{\partial I}{\partial x}} \neq \frac{\partial \bar{I}}{\partial \bar{x}}$$

Mean of instantaneous surface
Temperature perturbation
over a month
30°S to 40°S lat.

Surface temperature perturbation
using a monthly mean atmosphere
minus
mean of instantaneous perturbations

Brightness Temp. (K) — Wavenumber (cm⁻¹)

$$\frac{\partial \bar{I}}{\partial \bar{x}} - \overline{\frac{\partial I}{\partial x}}$$
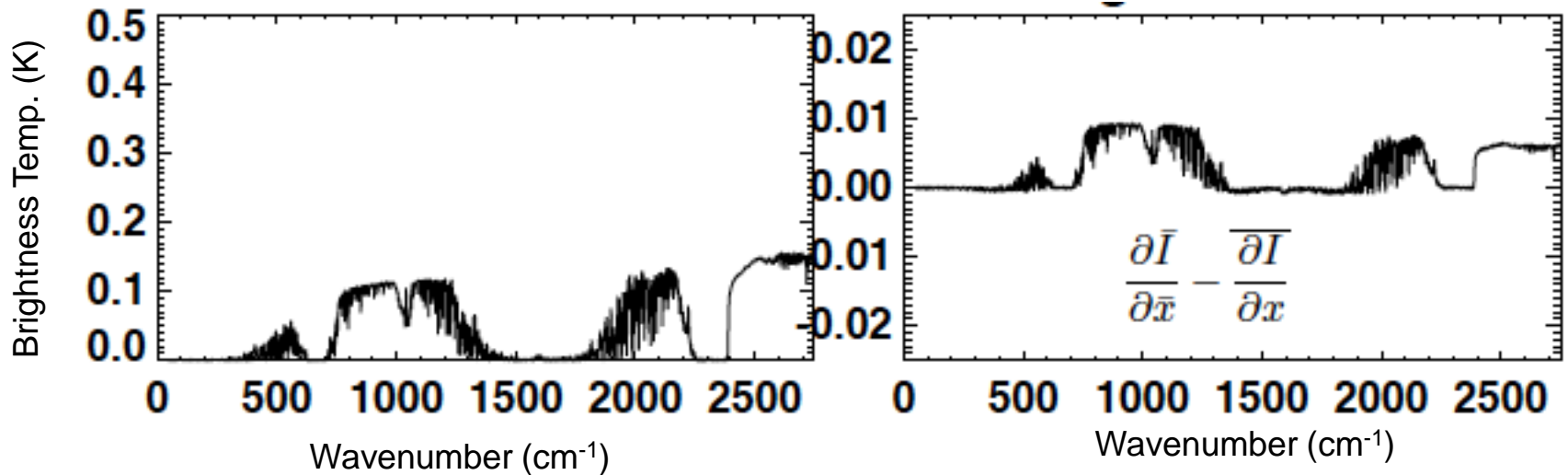
$$\Delta B_1 e^{-\tau_1} + \Delta B_2 e^{-\tau_2} + \dots \qquad \overline{\Delta B e^{-\tau}}$$

Global mean difference can be greater than 10%
(e.g. high cloud height change)

Necessary conditions we tested

- Sum of individual perturbations agrees with the spectral radiance change computed by perturbing all at once to within ~10%

- Spectral radiance changes linearly to atmospheric perturbations

- Spectral shapes are unique to be separated by a linear regression

- Mean of the instantaneous spectral radiance changes is not equal to the spectral radiance change computed from the mean atmosphere.
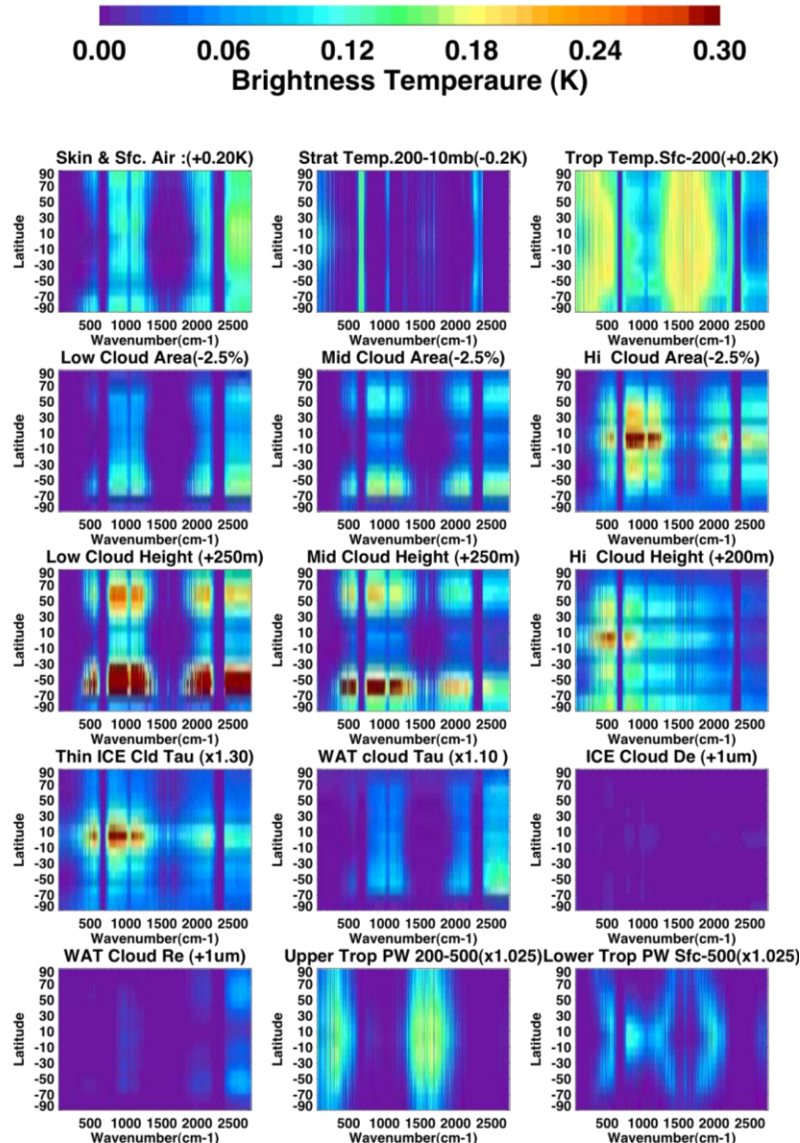
Spectral shape temporal variability

Black: global mean,
Blue: inter-month standard deviation × 5
Red: 2004-2003 annual mean difference ×5
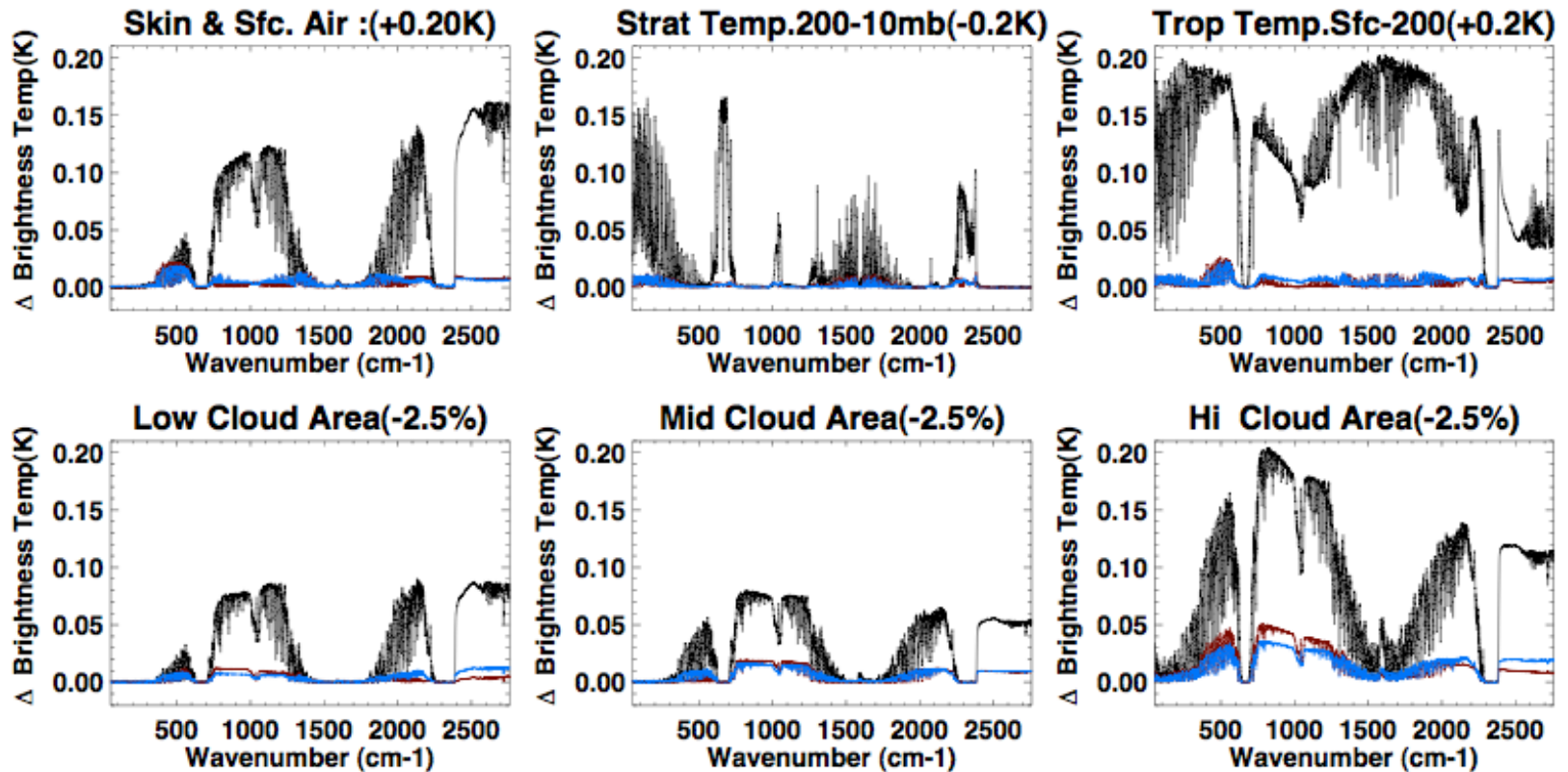
Zonal spectral shape
# (Spatial variability)

Annual mean spectral shape depends on latitude

Based on the results shown in the previous 2 slides, we use 10 degree zonal and monthly mean spectral shape in the following simulations

Retrieval of atmospheric changes from control run differences

- Compute TOA spectra using MODIS derived cloud properties and GEOS-4 temperature and humidity profiles

- Compute TOA radiance for 2003 and 2004 with a 20 km resolution.

- Spectral radiances are averaged to get 10 degree zonal and monthly mean spectral radiances.

- Take zonal and monthly mean differences between 2003 and 2004 control runs and treat as observed spectral changes.
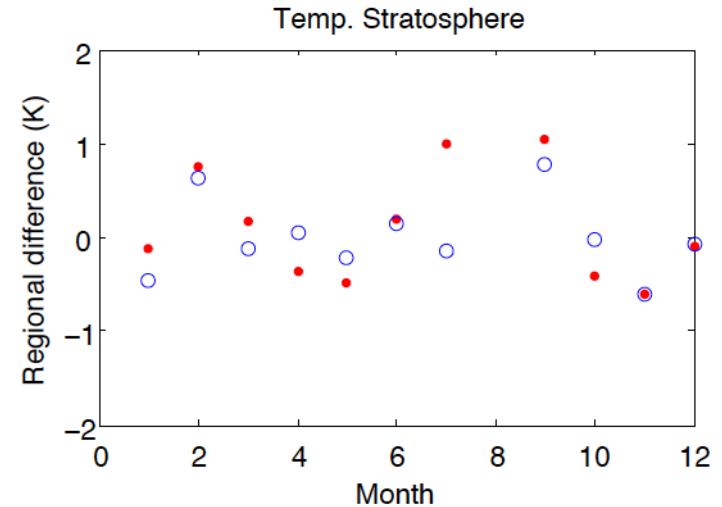
Retrieved vs. Truth
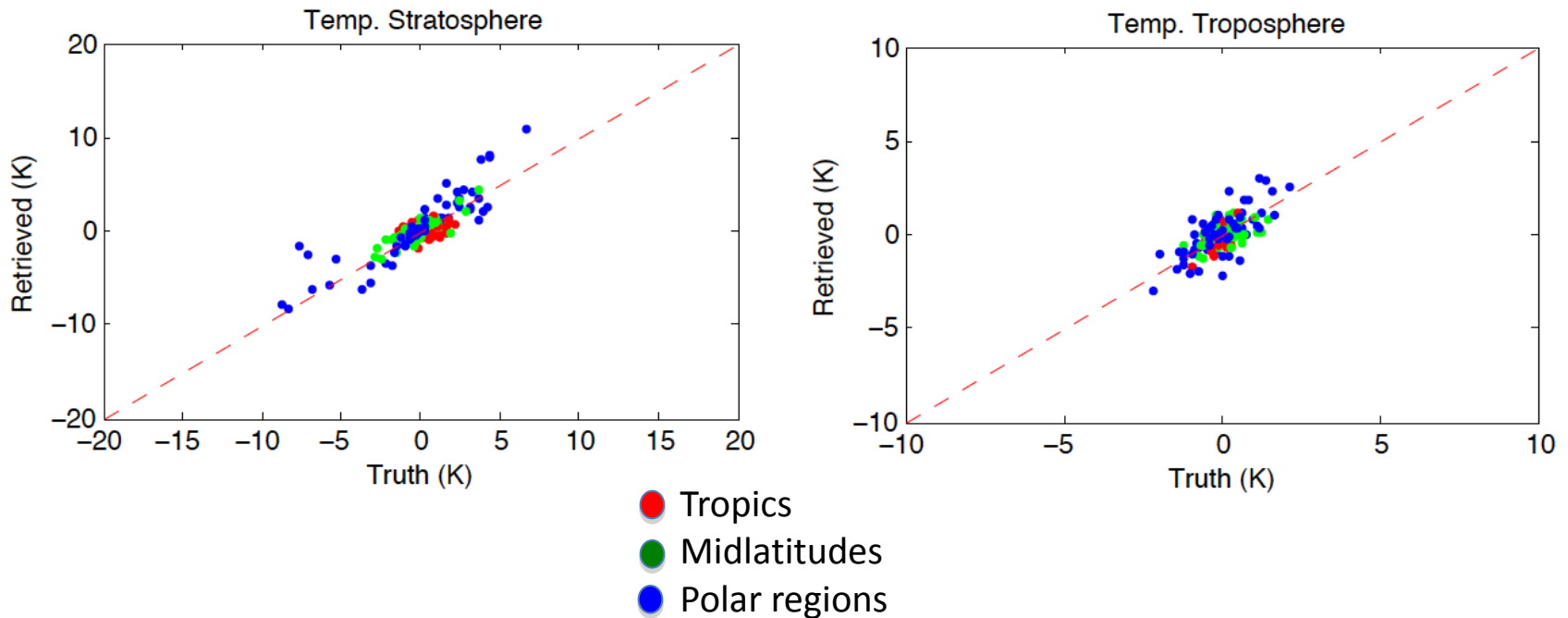
Retrieved stratospheric temperature and tropospheric temperature
from monthly 10 degree zonal mean spectral radiance is plotted against the truth
Each dot represent retrieved value from 10 degree zonal monthly spectral radiance
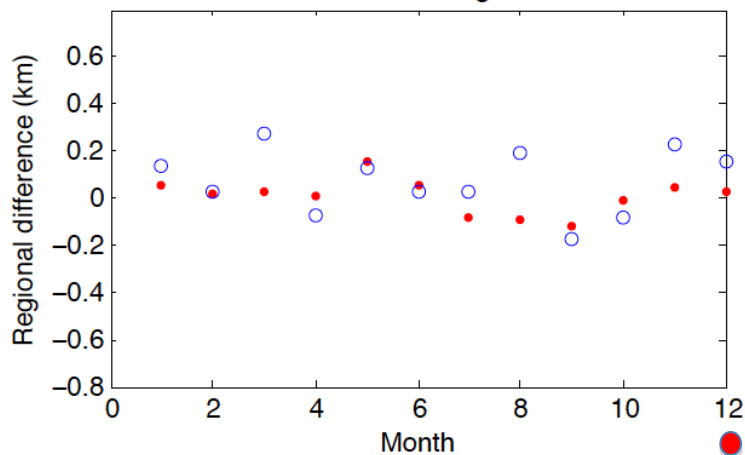Change. 1-year of data (i.e. $18 \times 12 = 216$ points) are used.
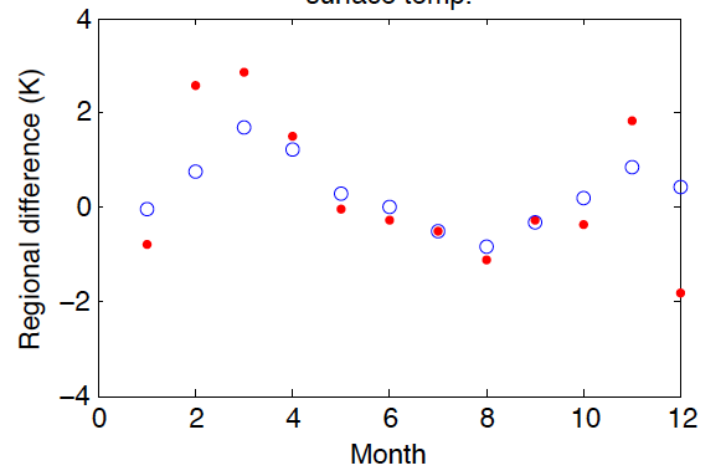
Regional

Tropics
Low cloud fraction
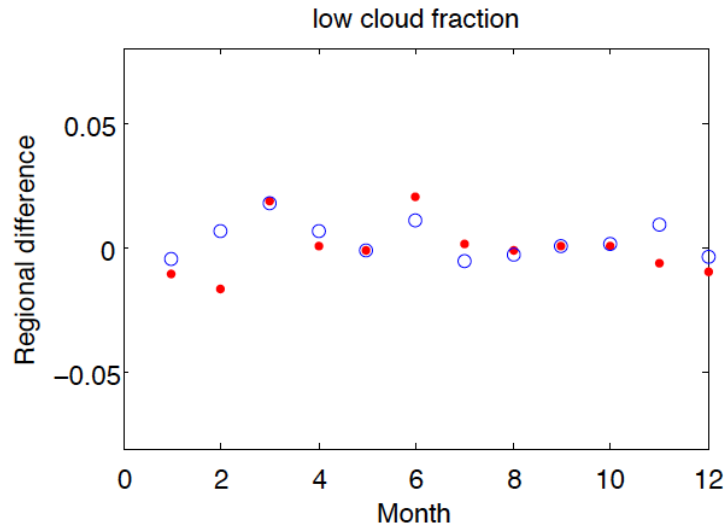
S.H. Mid-latitude
Stratospheric temperature
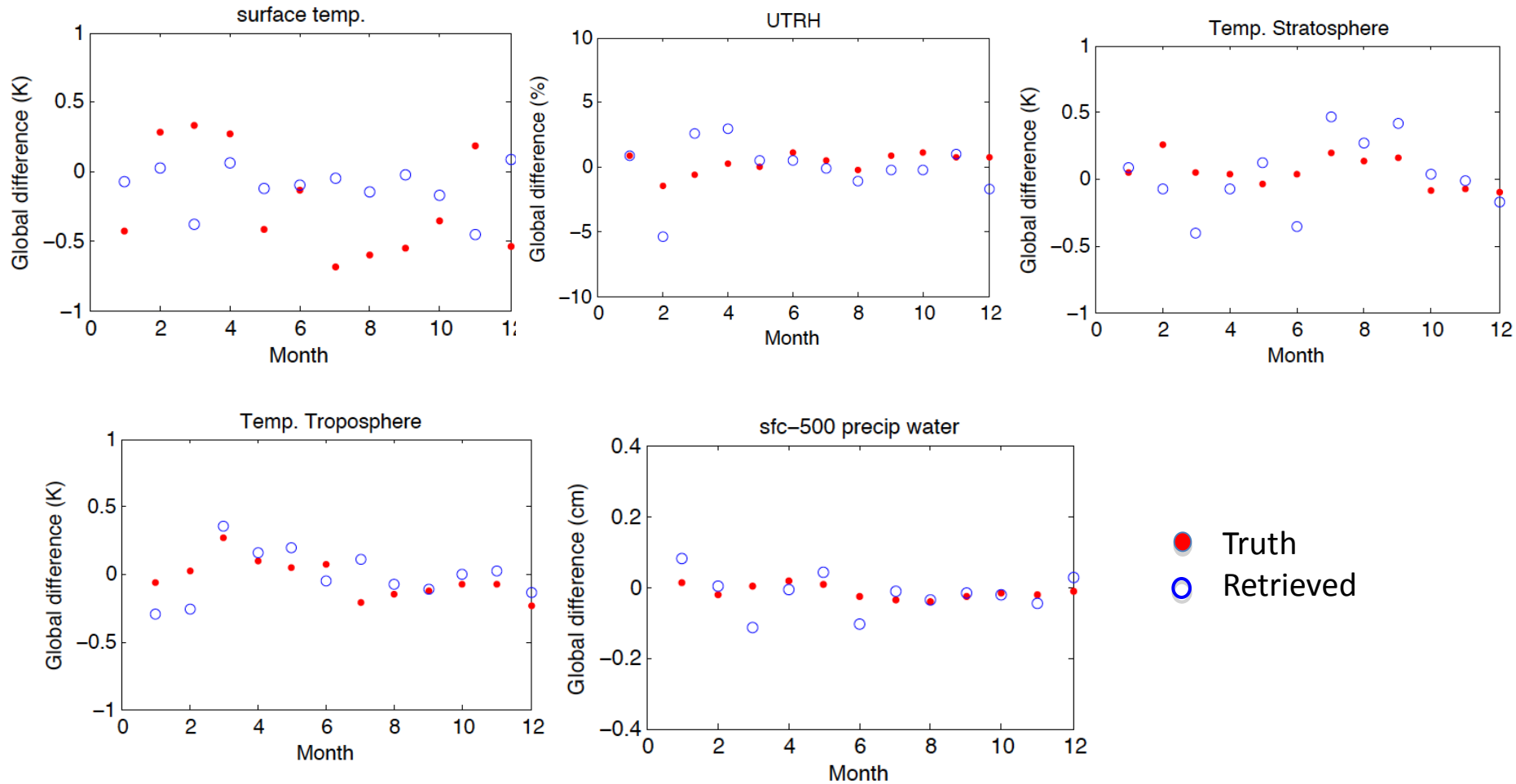
N.H. Mid-latitude
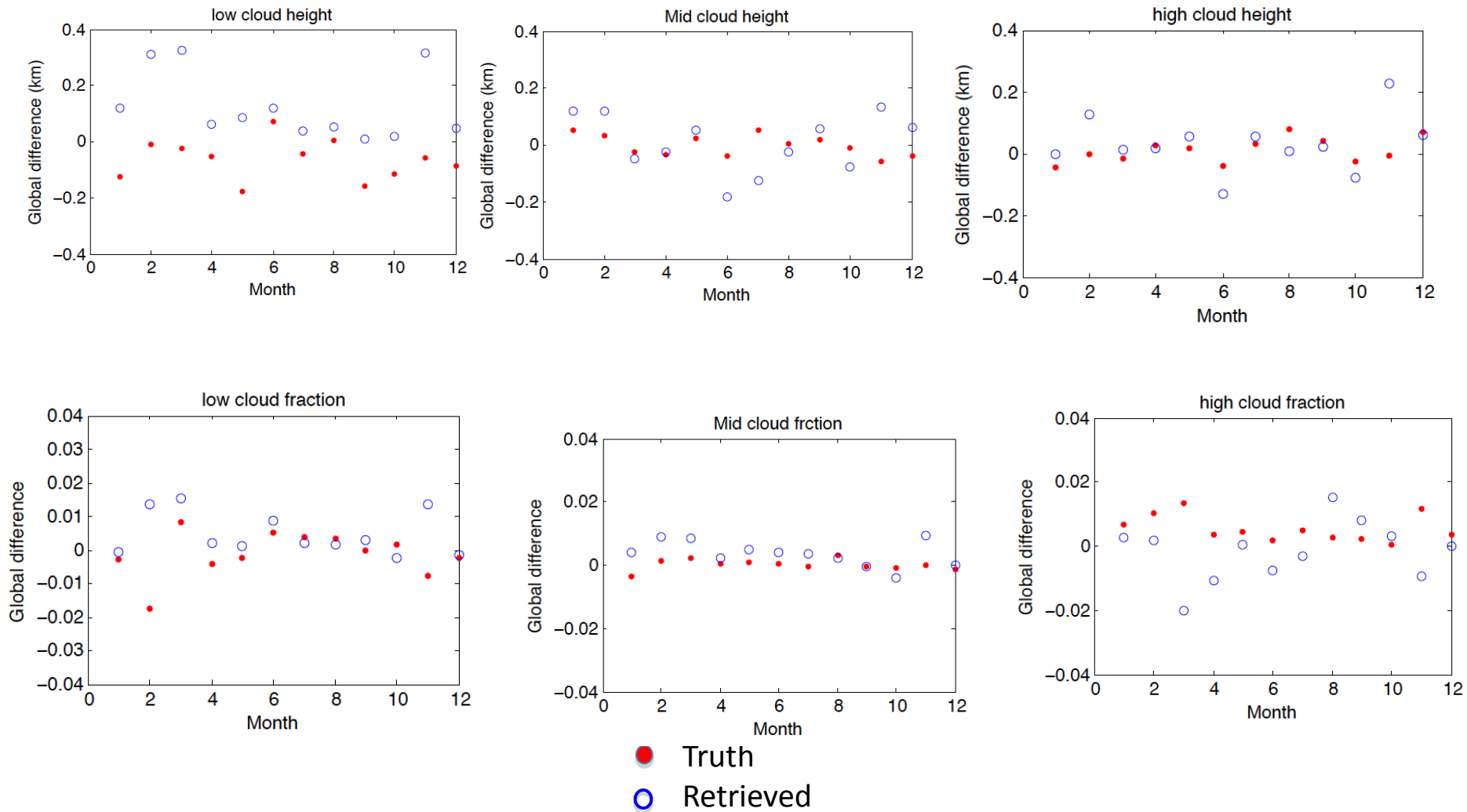Low cloud height

N.H. Midlatitude
Surface temperature

● Truth
○ Retrieved

Global temperature and humidity

Cloud height and fraction

Error is caused by…

- A coarse vertical resolution to compute spectral kernels

- Spectral kernel we used

$$\frac{1}{n}\left(\frac{\partial I_1}{\partial x_1} + \frac{\partial I_2}{\partial x_2} + ...\right)$$

While the exact form of kernel is

$$\overline{\Delta I} = \overline{\Delta x}\frac{1}{n}\left(\underbrace{\frac{\partial I_1}{\partial x_1}\frac{\overline{\Delta x_1}}{\overline{\Delta x}} + \frac{\partial I_2}{\partial x_2}\frac{\overline{\Delta x_2}}{\overline{\Delta x}} + ...}_{\overline{\frac{\partial I}{\partial x}}}\right)$$
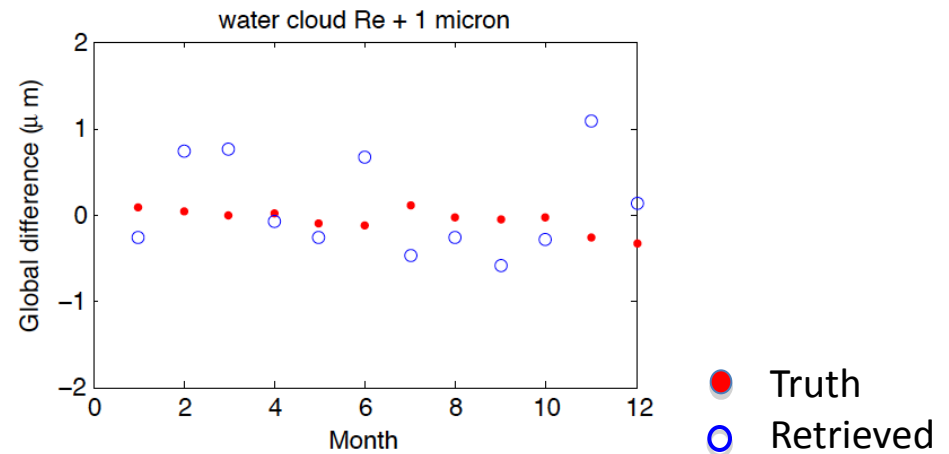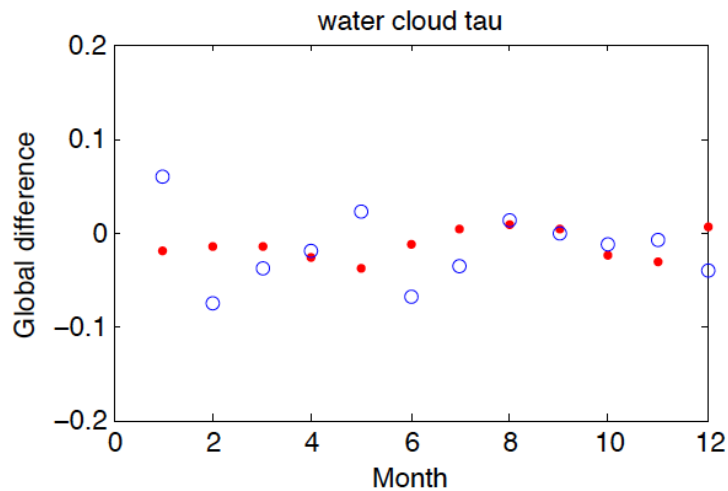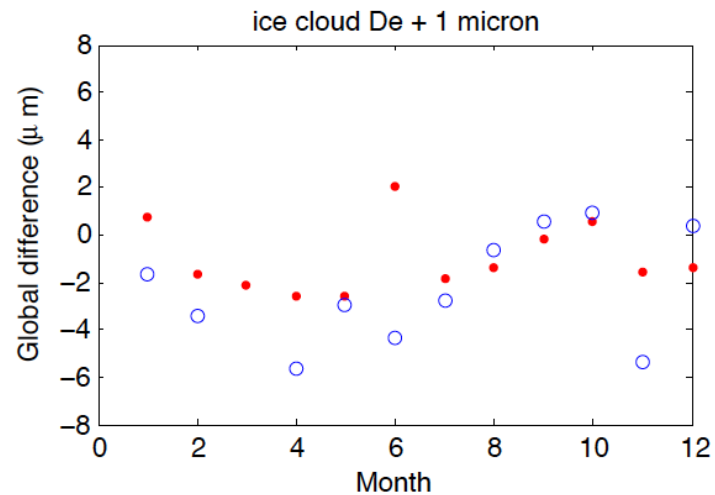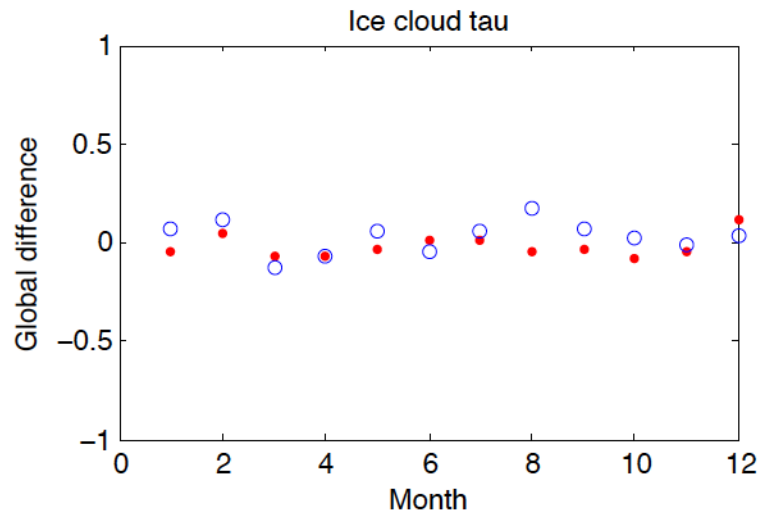
Summary and conclusions

- Necessary conditions to retrieve atmospheric properties from nadir view spectral radiance changes have been tested.

- Retrieval results using 10 degree zonal and monthly mean simulated spectral radiance changes between 2003 and 2004 are encouraging but more work is needed especially for cloud property retrievals.

Next step

- Use spectral shape computed from different spatial and temporal mean atmospheres.

- Use high vertical resolution to compute spectral changes.

- Understand the characteristic of retrieval error and develop a better constraint to reduce the error.

Backups

Cloud particle size and optical thickness

Ice cloud tau

ice cloud De + 1 micron

water cloud tau

water cloud Re + 1 micron

● Truth
○ Retrieved

Computing global mean property change versus time

- Retrieved monthly and 10 degree properties are averaged for global monthly mean property changes.

- Next three slides show comparisons of retrieved property change in 2004 from 2003 with true property changes as a function of month.

Fingerprinting strategy

- When CLARREO starts taking data, we train our radiative transfer model and determine

$$\delta \bar{I} = \bar{I}_{\mathrm{model}} - \bar{I}_{obs}$$

- Also, we build spectral radiative kernel from instantaneous observations

- We take a difference of CLARREO spectral radiance taking from a second period to the first period, of which the mean field is well understood.

- Apply linear regression   where ε is the modeling random error. The covariance matrix is based on our model training result and modeling random error from the first period. $\Delta \bar{I} = Sa + \varepsilon$

- Includes the non-linearity term in S as a component of spectral kernels.

$$a = (S^T \Sigma^{-1} S)^{-1} S^T \Sigma^{-1} Y$$

$$\Delta \bar{I}_{obs} = \bar{I}_{obs,2} - \bar{I}_{obs,1} = \sum \frac{\partial \bar{I}}{\partial x_i} a_i \Delta x_i + \Delta \bar{I}_{nl} + \delta \bar{I}$$

TOA spectral irradiance change

- Perturb temperature, humidity, and cloud properties using 2003 atmospheric and cloud properties.

- TOA spectral radiances are computed with a 20 km resolution and averaged over a 10 degree zonal and a month.

- TOA spectral radiance change (ΔI_λ) is computed by subtracting the control run TOA spectral radiance from the same zonal region and month.

Linear regression

- Using a matrix contains TOA spectral radiance changes, atmospheric changes are derived from all-sky monthly and 10 degree zonal mean spectral radiance change (Δi_λ) by a linear regression.

Cloud height and fraction